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Research on several interrelated topics is described in this report. These projects are focused on the analysis of feature and conjunction detection, models of selective attention, and curve tracing. One project examines the effects of a heterogeneous background on feature search. Another assesses spatial factors (such as target-distractor separation) in the detection of targets defined in terms of simple features. A third project has the goal of developing methods for determining the extent to which processing is serial or parallel. A fourth represents initial efforts to determine whether conjoined features are represented in retinotopic or spatiotopic "maps". A fifth explores top-down and bottom-up factors in visual search. A sixth makes use of an inhibitory priming method to test early-and late-selection models of selective attention. Finally, a project is reported in which the operation of visual curve tracing is studied. *Keywords: visual perception;*

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Abstract

Research on several interrelated topics is described in this report. These projects are focused on the analysis of feature and conjunction detection, models of selective attention, and curve tracing. One project examines the effects of a heterogeneous background on feature search. Another assesses spatial factors (such as target-distractor separation) in the detection of targets defined in terms of simple features. A third project has the goal of developing methods for determining the extent to which processing is serial or parallel. A fourth represents initial efforts to determine whether conjoined features are represented in retinotopic or spatiotopic "maps." A fifth explores top-down and bottom up factors in visual search. A sixth makes use of an inhibitory priming method to test early- and late-selection models of selective attention. Finally, a project is reported in which the operation of visual curve tracing is studied.

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Preattentive and Attentive Visual Information Processing

During the second year of this grant several projects were completed and several others were initiated (and have already begun to bear fruit). For the purpose of this annual report these projects will be categorized in the following way: Feature detection; conjunction detection; early vs. late selection; curve tracing.

Feature detection

Nontarget heterogeneity effects in feature detection

Treisman's feature integration theory (Treisman & Souther, 1985) proposed that different perceptual features are registered separately in different feature maps. Features anywhere in the visual field produce activity in their corresponding feature maps, and this process occurs simultaneously (in parallel) across the visual field. Thus, feature detection can be accomplished rapidly and preattentively because all that is required is to interrogate the map corresponding to the feature of interest. Folk (1987) extended the range of application of this model by incorporating the notion of coarse coding, which allows for features to contribute activity not only to their "own" feature map, but also to maps corresponding to similar features. Thus, a diagonal line segment would register most actively on the "diagonal map," but would also produce detectable levels of activation on "horizontal" and "vertical" maps. Using this model, Folk was able to account for differences in patterns of performance on same-different tasks (which require a comparison of activity in two maps) compared to present-absent tasks (which require only monitoring a feature map).

According to the model, these maps are independent of one another in the sense that search for a target defined on the basis of a single feature can be accomplished simply by monitoring the map that is maximally responsive to that feature, and ignoring all others. Is it really possible to simply ignore irrelevant feature maps?

To answer this question, Bill Bacon and I conducted an experiment in which subjects made a same-different judgement in response to a number of horizontal and/or vertical line segments flashed briefly on a screen. The targets on the screen might be all horizontal or all vertical (same response) or all horizontal except for a single vertical, or all vertical except for a single horizontal (different response). The critical manipulation in this experiment involved the background elements. Any screen location that did not contain a target contained a diagonal line which was to be ignored. In the homogeneous background condition, all background diagonals were the same (all 45° or all 135°). In the heterogeneous background condition, the background diagonals were randomly mixed (some 45° and some 135°). According to the model above, subjects need only monitor the horizontal and vertical maps, and can simply ignore the irrelevant feature maps. If this is

true, then performance on the task ought to be identical whether the background is homogeneous or heterogeneous.

It turns out that the task is much more difficult with a heterogeneous background (cf. Duncan & Humphreys, in press). In fact, the heterogeneous condition was 274 ms slower than the homogeneous condition. Mean RT's were 797 ms for homogeneous background, and 1071 ms for heterogeneous background. Apparently, it is too simplistic to claim that the kind of perceptual tasks we have investigated can be solved by examining only a single relevant map.

Local processing in feature detection

The experiment described above suggests that the processing of features in the visual field somehow depends on the presence of other features. What is the extent of this interdependence? Recently, there has been a claim of a rather profound sort of interdependence. Specifically, it has been claimed that in order for a feature to be detected preattentively (in parallel), it must be possible to compute a feature gradient between that feature and a neighboring stimulus. In other words, a target will not be detected preattentively unless it is within some small critical distance of a nontarget.

This claim was made by Sagi and Julesz (1987), on the basis of findings from a same/different task in which they varied the density of the element display. In their task, subjects searched for a line segment of known orientation against a background of line segments of some other orientation. There were two display configurations. In the large minimal interline spacing condition, the display consisted of a 7 x 7 array of possible element locations. In the small minimal interline spacing condition, the display consisted of a 10 x 10 array of possible element locations, squeezed into approximately the same space. Stimuli were presented briefly, and after some stimulus onset asynchrony (SOA), followed by a pattern mask. The performance measure was percent correct. They found that for both display configurations, performance declined from a display size of 2 to a display size of around 30. However, at that display size, performance on the two configurations began to diverge. In the large minimal interline spacing condition, performance continued to decline up through the largest display size. However, in the small minimal interline spacing condition, performance began to improve, and continued to improve up to the largest possible display size. The investigators note that this improvement can be predicted on the basis of the increasing probability that there will be a nontarget within two degrees of visual angle from the target. Therefore, they conclude that feature detection has a short-range limitation. If these conclusions are correct, they would have important theoretical implications. They bring into question the whole notion of searching for features by monitoring feature maps.

However, other interpretations of the Sagi and Julesz results

are possible. Since Sagi and Julesz had to infer target-nontarget separation from display size and density, it is possible that their findings were caused by some other factor that varied with display size, such as nontarget-nontarget separation, which might be responsible for nontarget grouping. In order to disentangle these factors, Bacon and I have conducted a series of experiments (in both the same-different and present-absent paradigms) in which we independently manipulated the target-nontarget separation and the display size. We used square patches of color as stimuli and varied the number of elements from 2 to 32. Target-nontarget separation was controlled by choosing the location for the target first, and then placing constraints on the possible locations of the nontargets. Thus, target-nontarget separation did not necessarily decrease as display size increased, because the window of locations around the target was directly controlled in the experiment. If in fact there is a short-range limitation in feature detection, then at any given display size, performance should decline as separation increases.

We found that mean RT's were essentially identical whether separation was small (.6 deg) intermediate (2.0 deg) or large (3.4 deg). Since separation was manipulated directly, rather than inferred from element numerosity, this is strong evidence against a short-range limitation. Not only was there no evidence of a qualitative change in processing (i.e., from parallel to serial) at large separation, there was no evidence of any kind of dependence on local processes (i.e., not even a hindered parallel process).

Further, we found an inverse relationship between RT and numerosity. Note that it was this very relationship that led Sagi and Julesz (1987) to assert the importance of target-nontarget proximity. It is interesting that our task still showed this effect, even though the correlation between numerosity and target-nontarget separation has been experimentally eliminated. This suggests that the improved performance with increasing numerosity that we and Sagi and Julesz found must be due to some other factor (other than target-nontarget separation) that varies with numerosity.

Further experiments are planned in which less discriminable color pairs are used, and with easy and difficult orientation discriminations. We also plan to explore the basis of the inverse relation between RT and display size. Specifically, nontarget grouping will be explored.

Conjunction detection

Assessing Parallel vs. Serial Processing.

A central feature of feature integration theory is that feature conjunctions need to be processed one location at a time. Is this correct? Several recent findings suggest that it may not

be. For example, Egeth, Virzi, and Garbart (1984) showed that subjects do not have to search randomly through stimulus locations until they find the target but instead may be guided by one of the conjunction target's features.

A second set of results that challenges the serial model comes from very recent work by Wolfe, Cave, and Franzel (in press; see also Nakayama & Silverman, 1986). They found that the functions relating RT to display size were often flat in conjunction searches, as they were for feature searches. Indeed, they even found flat functions when a target was defined as a conjunction of three features--for example small, red, X. These authors proposed a model in which both top-down and bottom-up processes contribute to the search process. This model does not replace the idea that attention is required to conjoin the features of an item. Instead they argue in favor of an intelligent parallel stage that under some conditions is extremely efficient at passing targets to the serial stage. An interesting feature of this model is that no decisions are made preattentively. Even feature targets must be examined by the serial stage before a response can be made.

Finally, we turn to a paper by Pashler (1987) which focused on the 2:1 ratio of target absent to target present slopes, which is often taken as the signature of serial processing. He noted that calculation of these slopes is usually across all levels of display size. However, when the data are examined separately for small display sizes (i.e., 2, 4, and 8) the slope ratios were closer to 1:1 than 2:1. This might suggest that search is serial exhaustive for small displays and serial self-terminating for large displays. However, Pashler also included a second target on some trials and showed a redundancy benefit, that is, mean RT was faster when there were two targets rather than just one in the display. A redundancy benefit is incompatible with a serial exhaustive model. In sum, Pashler suggested that his data implied parallel processing within relatively small clumps of items, say up to eight items in size, but serial and self terminating processing across clumps.

Problems of interpretation. The redundant targets paradigm that Pashler used is a very useful supplement to the standard procedure of just measuring mean RT as a function of overall display size. Townsend has pointed out the problems with that analysis; in short, the usual increasing function does not necessarily imply serial processing.

Unfortunately, even the redundant targets experiment has problems. It turns out that it is not sufficient to simply compare overall mean RTs, as there are certain artifacts that can produce a redundancy benefit. Suppose, for example, that for each subject there is a particular favored position in the display that is processed more quickly than the others, perhaps because it is inspected first in a serial scan. The greater the number of targets the greater the probability that one of them will be in the favored position and thus the faster the mean RT. Some analyses

have been proposed to deal with this problem (e.g., Biederman & Checkosky, 1970) but there is another even more insidious problem lurking. There may be a favored position that it is not fixed but varies randomly over trials. Van der Heijden et al. (1983) proposed an analysis to test this artifact. However, my colleagues and I (Mullin, Egeth, & Mordkoff, 1988) have shown that this proposed analysis is wrong. We did a computer simulation in which we generated data for an unlimited capacity parallel processing model and found that the Van der Heijden et al. analysis incorrectly concluded it had a random favored position. The citation for this work is: Mullin, P. A., Egeth, H. E., & Mordkoff, J. T. (1988). Perception & Psychophysics, 43, 607-610.

Coactivation. Is there any way to counter this somewhat disheartening turn of events? One approach that recommends itself has been described in some detail by Miller (e.g., 1982). Miller's method involves a search for data that violate a particular mathematical inequality. Such violations can be said to be due to "coactivation."

The approaches we have been considering so far have conceived of the stimuli in various locations as producing separate activations. On any particular trial responding is controlled by the detection of a signal on one channel or another. These models are typically race models, because the response to redundant signals is determined by the fastest among several simultaneous response activation processes. For familiar statistical reasons, the winning time in a race is faster than the mean time for any of the competitors, as long as the completion time distributions overlap. Thus the standard redundancy benefit is the result of what has been called statistical facilitation.

An alternative conception is that activation from separate channels may combine to satisfy a single criterion for response initiation. This is what Miller has referred to as coactivation. Naturally, activation builds faster when it is provided on several channels rather than just one. This provides an alternative explanation for redundancy benefit. Specifically, on a coactivation model it may be the case that the fastest times in a multiple target condition are faster than the fastest times in any of the corresponding single target condition, because activation is summed across targets.

More formally and more generally, Miller has shown that the following relations hold for separate activation models. Assume here that there are two possible target locations, 1 and 2.

$$P(RT < t | S_1 \text{ and } S_2) = P(RT < t | S_1) + P(RT < t | S_2) \\ - P[(RT < t | S_1) \text{ and } (RT < t | S_2)]$$

The left side of the equation corresponds to the cumulative density function (CDF) of RT on redundant signal trials, and the first two

terms on the right correspond to the CDFs for the two single target conditions. The final term reflects the correlation between the two activations.

From the preceding basic equation a prediction can be derived for all separate activation models:

$$P(RT < t | S_1 \text{ and } S_2) \leq P(RT < t | S_1) + P(RT < t | S_2)$$

This is true because the rightmost term in the basic equation above is greater than or equal to zero.

What this last inequality says is that if a separate activations model holds, and we plot the CDF for redundant target trials and compare it to the sum of the single target CDFs, then the curve for redundant trials should be everywhere to the right of the curve representing the sum of the two individual stimuli. However, if coactivation occurs the curves might well cross. That is, at the short RT end of the distribution the curve for the redundant target trials might be to the left of the curve representing the sum of the two individual stimuli.

Experiment. To turn now to our first coactivation experiment using conjunctively defined targets, on each trial we presented subjects with two stimuli, one above the other. Subjects simply had to indicate whether or not there was a red X present. The nontargets were red Os and green Xs. Here are some sample stimuli:

Yes			No		
Red X	Green X	Red X	Green X	Red O	Red O
Red X	Red X	Red O	Green X	Red O	Green X

Note in particular the last example. It does not contain a target, but it does contain a red item and an X. Such trials ensure that subjects search for a red X and not just the presence of X and the presence of redness.

Subjects served in a single session, of 480 trials.

All subjects displayed a significant redundancy benefit, and thus provide some evidence of parallel processing. However, as mentioned earlier, the redundant targets paradigm is subject to strategic artifacts. To avoid these artifacts, tests for coactivation--a strong test of parallel processing--were also conducted.

The RT distributions were divided into ten bins centered at 5%, 15%, 25%, etc. Significant evidence for coactivation was found at both the 5% and 15% bins. That is, for the shorter RTs in the distribution the mean RT for the redundant trials was significantly

faster ($p < .0005$) than the mean RT derived from the distribution representing the sum of the individual stimulus conditions.

The redundant target condition yielded responses that were too fast to be explained by any serial model. Our conclusion from these results is that at least two objects may simultaneously have their color and form conjoined into a unified percept. This is inconsistent with models such as those proposed by Treisman and Gelade (1980) and by Wolfe, Cave, & Franzel (in press), among others, in which stimuli must be passed to a serial processor before a response can be activated. Instead, the data suggest that some degree of parallel processing is possible. How much? We can't say yet. It is possible that as many as eight stimuli can be examined in a glance, as Pashler has argued, but a definitive result awaits further research with methods designed to eliminate the artifacts that plague many existing paradigms. (A variety of follow-up experiments would be desirable here. In particular, the literature on coactivation and redundancy gain suggests the value of testing with go-no go and forced-choice tasks as well as the two button present absent-response used in the preliminary experiment. In addition we should explore the role of distracting nontarget stimuli in producing redundancy benefit.)

This work was reported at the recent E.P.A. meeting. Mordkoff, J. T., Yantis, S., & Egeth, H. E. (1989). Parallel processing of color and form [Abstract]. Proceedings and Abstracts of the Annual Meeting of the Eastern Psychological Association, 60, 57.

The Nature of Location Codes in Visual Search

One issue pursued during this time period has to do with the nature of the location code used to bind features together. Several models of attention and visual search have been developed in recent years in which features such as color, shape, orientation, etc., are initially encoded in separate maps, and then are conjoined in some form of master map. Attention is seen as the glue that binds the different features of a given object together in the master map in these models, but little work has been done on the question of what the nature of the location code might be. For example, it might be that the code is spatiotopic, referring to a location in the physical environment; retinotopic, referring to a location on the retina; or some more abstract representation combining information from these.

Dale Dagenbach and I have done some pilot work pursuing this issue by using moving displays. The general logic was that if location codes were either retinotopic or spatiotopic, an abrupt movement of a display should hamper a search process. On the other hand, if the codes were retinotopic, a smoothly moving display might be searched efficiently. A more abstract form of location code might be able to handle movement of either kind.

Displays consisting of 2, 4, 6, or 8 items were presented, with

L's serving as distractors and T's as the target. In the first experiment, the display moved abruptly from one location to another on some trials, and blinked in place on others. The data from this experiment were surprising in that they indicated that subjects actually searched the moving displays slightly faster than the displays that blinked in place. The mean search time for target present trials with moving displays was 554 msec, and for blinking displays it was 568 msec. Similarly, the mean search time for trials with no targets and moving displays was 592 msec, and for blinking displays it was 603 msec.

This finding seems incongruous in that abrupt movement should not lead to more efficient search, regardless of the nature of the location code. The data are somewhat noisy, and would have to be replicated before accepting this finding. If it is accurate, it poses an interesting puzzle for search models to consider. Future experiments in this line may investigate possible artifacts giving rise to the effect, and variations in the task that might allow better insight into the original issue.

Top-Down and Bottom-Up Factors in Visual Search

A series of reaction time (RT) experiments is being conducted by Bruce Hamill to explore what happens when subjects are set to expect certain kinds of target/distractor conditions, and a few trials that violate those expectations are inserted into trial blocks. Most of the trials in each block are standard feature or conjunction search trials ("expected" trials) using combinations of selected targets and distractors. However, on a few trials ("surprise" trials) in each block, between-block manipulations of either the target or the distractors are made, introducing unexpected target/distractor combinations to the subject. The experiments include both feature search (for color and for shape) and conjunction search (combining color and shape features).

Feature search, at least for the features used in these experiments, is usually viewed as preattentive, involving unlimited-capacity parallel search through elements in a display. Egeth and Bradshaw (reported in Egeth, 1977) found differential effects of set, or foreknowledge, in mixed versus pure lists of stimuli that were composed of features (color and size) that are ordinarily considered to be handled by spatially parallel processes. They note that "even presumably preattentive discriminations can be influenced by set" (p. 301).

Cave and Wolfe (1989) have proposed a "guided search" model of visual attention that employs parallel and serial search processes to find targets defined by combinations of features among distractors in displays of various sizes. Data-driven ("bottom-up") and knowledge-based ("top-down") parallel processes generate activations in the relevant spatial "feature maps"; the activation levels are summed across features in a "master map" indicating the relative probability that a given combination of features defines the target. A contemporaneous serial search process selects that

feature combination in the master map having the highest activation level as the best candidate target; if it selects a non-target, it continues its search until it finds the target. This model can account for a wide range of empirical results concerning parallel and serial search processes.

If the Cave and Wolfe model is correct, manipulations of target and distractor features in feature search and conjunction search procedures should produce dissociations that can be attributed to the bottom-up or top-down processes of the parallel stage or to the serial stage of processing. It is these dissociations that are being explored in this series of experiments that has just recently gotten under way.

Early vs. late selection

Inhibitory Priming Measures of Selective Attention

A longstanding issue in human attention concerns the locus of selective attention. In general, this question is framed in terms of how much information is extracted about unattended items in various experimental paradigms. Early selection theories suggest that gross physical features of the distractors are available, but that higher level semantic information is not, whereas late selection theories suggest that unattended items also receive semantic processing. The question becomes one of determining how to measure whether semantic activation of unattended items has occurred.

A promising technique was recently described by Tipper and his colleagues. Their claim is that if an item is intentionally ignored in one display, responses to that same item or a related item which serve as a target in the subsequent display will be inhibited. This technique has been described as showing evidence of semantic processing in paradigms where other measures had failed to obtain any. For example, Francolini and Egeth (1981) presented displays of red letters and black numbers to subjects, whose job was to count the red letters. Their results indicated that the identity of the black numbers did not affect the subjects' response latencies. Driver and Tipper (1989) have recently reported a variation of this study in which they assess the effect of the identity of the black numbers on one trial on response latencies to the red letters on the subsequent trial. Their claim is that when the black numbers' identity is the same as the response required on the subsequent trial, responses are slower. Thus, having the ignored black characters be the number "4" on one trial will result in a slower response when there are 4 red letters on the next trial. Such results are in accordance with the predictions of late selection theory, in contrast to those of Francolini and Egeth that have been seen as strongly supporting early selection.

The Tipper findings raise the question of how far one can push

late selection theory claims. For example, if two different distractor identities were present, would they both produce inhibition? If so, how much? One half of that produced when there is just one identity, or the same amount? If the distractor is in a distinctly different location from the attended item, will it still produce an effect?

Dagenbach and I have attempted to pursue these questions in several different experiments. The general logic has been to present two pairs of letters on a prime trial. Each pair contains a red letter and a green letter, and one of the pairs is cued at the onset of the trial to indicate that it will contain the target. The subject's job is to respond to the red letter in the cued pair by pressing a key to indicate its identity. Another pair of letters appears after the response to the first display, with a red target. Inhibitory priming effects on responses to this target are assessed. The inhibitory priming can potentially arise from the green letter in the cued pair on the preceding display on some trials, or from the green letter from the uncued pair on others. Inhibitory effects from the green letter in the cued pair would be similar to the effect reported by Tipper. Inhibitory priming from the green letter in the ignored pair of letters would provide strong support for a late selection account. Failure to get it would constrain such an account.

The short answer is that in a variety of experiments using slightly different presentation conditions, with and without a subsequent mask, negative priming effects from the green letter in the ignored pair were not obtained. However, we have also been unable to replicate any of the inhibitory priming effects reported by Tipper, leaving the whole issue up in the air. To be fair, our data have contained hints of the effect. However, it has never approached statistical significance.

The data from 3 experiments with a reasonable number of subjects look as follows:

	Control	Within-Pair Distractor	Between-Pair Distractor
Exp1	435	438	430
Exp2	467	471	472
Exp3	426	426	436

This failure to get the effect led to a more direct replication of one of Tipper's experiments, using just two letters, one of which is the target, and one of which is the distractor. The priming effect from the distractor to the target on the subsequent trial in this case was + 5 msec, in contrast to the inhibition effect reported by Tipper. This failure to replicate follows on the heels of an earlier failure to replicate in Egeth's lab, leaving the existence of the inhibitory priming effect in doubt in our minds.

Curve tracing

People easily extract spatial information from a visual scene. With little apparent effort, they determine what object is to the left of the circle, which letter is inside the circle, whether the two blue letters both fall on the same contour, and so forth. As pointed out by Ullman (1984), the apparent ease with such tasks are solved belies their computational complexity. He proposed that the perception of certain spatial relations is accomplished by the output of corresponding "visual routines." Each routine is an ordered assembly of elementary operations, and its assembly is context driven. Each operation is applied to the base representation (e.g., Marr's two-and-a-half-D sketch, 1982) resulting from "bottom-up" processing or to successive representations resulting from the application of previous routines. Our ability to correctly perceive large numbers and varieties of spatial relations is, by this approach, governed by our capacity to generate numerous and appropriate routines from a relatively small number of basic operations. Therefore, identification and analysis of these elementary operations and the manner of their assembly into routines are important goals in the study of pattern recognition and space perception.

Recently Jolicoeur, Ullman, and Mackay (1986) reported that people rely on a "curve tracing" operation to determine certain spatial relations. When subjects decided as quickly as possible if two Xs fell on the same curve, reaction time (RT) increased monotonically with the separation between the Xs along the curve, even though the physical separation between the Xs was held constant (see Figure 1). Because the stimuli were presented for 250 ms for half the subjects, eye-movement explanations were ruled out.

RTs for the different stimuli were less systematic perhaps because an explicit tracing route was unavailable for those stimuli. When subjects in a second experiment decided if the contour between the two X's did or did not contain a small gap, RT increased monotonically with the separation of the X's along the contour for both the yes and no conditions. The increasing RT functions across the two experiments accelerated appreciably, but, on average, the rate of tracing was 40 degrees visual angle per second.

The stimuli used by Jolicoeur et al. were carefully constructed to rule out alternative explanations of the increasing RT functions. However, the stimuli probably favored a curve tracing solution. In each case the two contours were so interwoven that curve tracing might have been necessary to tell them apart. Also, one X was always located at the fixation point on one of the contours. This arrangement may have induced subjects to locate the second X by shifting attention along the connecting curve. The goal of the present study was to test the generality of the curve tracing operation with stimuli that, on an intuitive basis, seemed less likely to require it.

We attempted replication of the Jolicoeur et al. findings with elementary stimuli. Each stimulus consisted of two curves and two X's (see figures 2 and 3), and the task was to decide as quickly as possible if the two Xs fell on the same or different curves. In this case, however, the stimuli were simple; neither X was located at the fixation point, and the contours were noninterweaving. Indeed, it is the very simplicity of the stimuli that is the point of study. Ullman argues that curve tracing is a basic operation. If this is the case, it should occur even with stimuli that appear to be so simple as not to require it. In short, we are attempting to provide a stringent test of the hypothesis that curve tracing is an elementary operation. Note, however, that our test is asymmetric in nature. If the results are consistent with the curve tracing hypothesis, then we will have evidence supporting the notion that it is basic. If the results do not show the hallmark of curve tracing (increasing some RT with increasing distance), this will not necessarily falsify the hypothesis. It is possible that there are some other basic processes that can be used to solve the perceptual problems that we posed to our subjects. These other basic processes might conceivably operate in parallel with curve tracing, with the fastest process determining the RT on a trial. Thus, if curve tracing is relatively slow, it might not be detectable.

In our first experiment we obtained data consistent with curve tracing, i.e., same RT increased with separation of the Xs along the same curve. Different RT decreased as separation increased. (To be clear about what we mean by separation increasing on different trials, refer to the sample stimuli in Figure 3.)

In the next experiment we replicated the first experiment with a single important change--the stimuli were optically doubled in size. The data were similar in pattern to those of the previous experiment, but the rate of scanning was doubled (if measured along the curve, say in cm/sec). To express this point differently, if we consider the stimulus in polar coordinates, the analog operations in experiments 1 and 2 were constant in speed when measured with respect to the angle separating the Xs.

There is something counterintuitive about the preceding results. The stimuli are so simple that it seems possible that subjects could and would solve the task more directly, perhaps by noting the "axis" defined by the gap between the curves and then simply determining whether the two Xs fall on the same or opposite sides of the gap. Two additional experiments were conducted to test this and other possible strategies for performing in our task. The results indicated that strategic or judgmental factors may well be responsible for the different data, but not the same data.

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In subsequent experiments done with Ho-wan Kwak, we have found that curve tracing can be a self-terminating operation (contrary to the report of Jolicoeur, Ullman, & Mackay, 1986). We have also gone on to study more complex figures. Our initial results are commensurately complex; it appears that with such stimuli curve tracing can coexist with (better, race with) other basic operations (such as the use of the gap axis strategy mentioned above). This work is continuing.

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